Avionic Systems Division
NASA Johnson Space Center, Houston, Texas

NASA-JSC Wireless Sensor Network Activities Update

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CCDSS Wireless Working Group Face-to-Face
Darmstadt, Germany

April 16, 2012

Agenda

- **Update on ZigBee Pro, ISA100.11a co-existence studies**
- **Update on JSC Modular Wireless Instrumentation (“SSIART-NASA”)**
- **Update on JSC High-Speed Wireless Instrumentation Needs**

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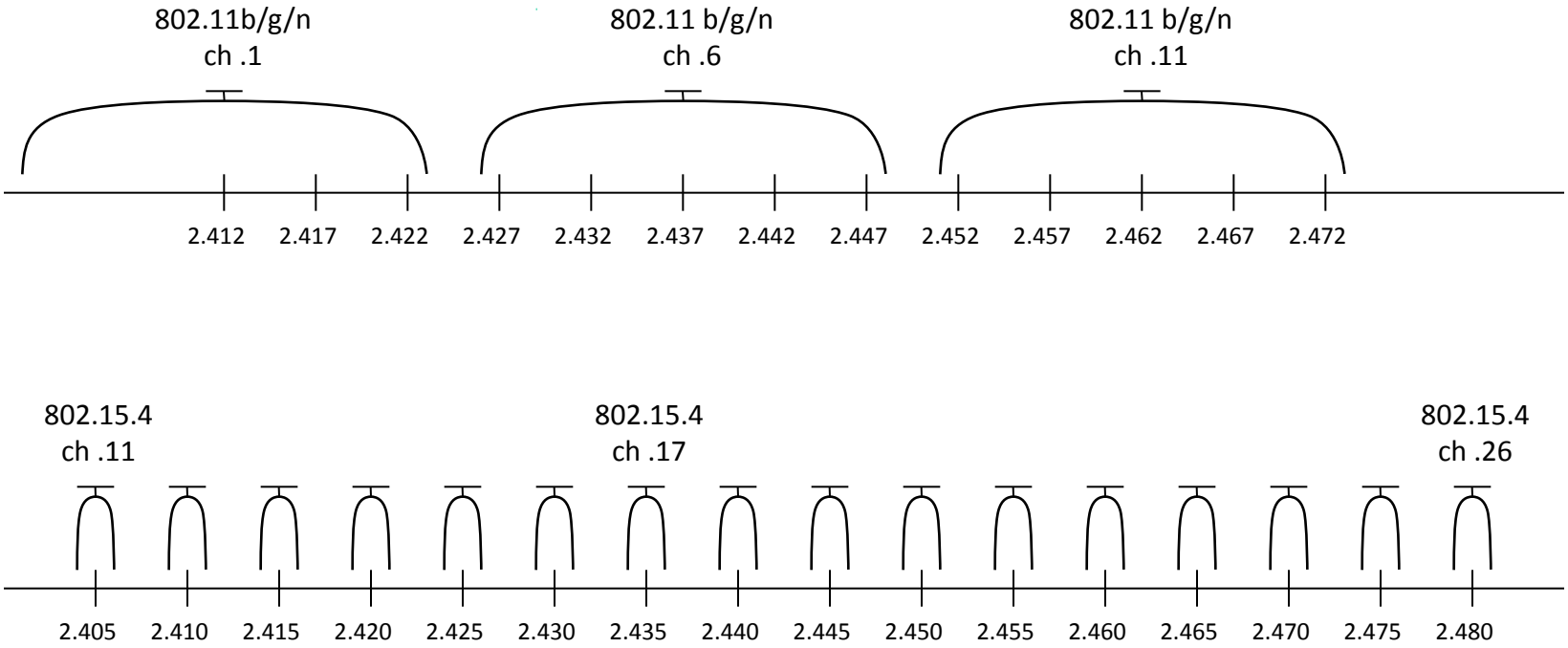
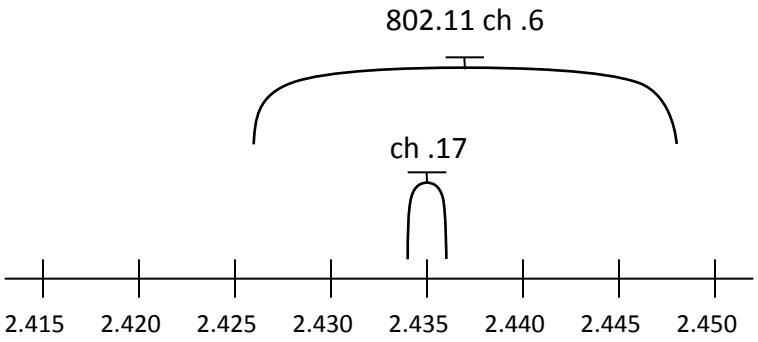
Update on ZigBee Pro, ISA100.11a Co-Existence Studies

802.15.4, 802.11 Co-existence

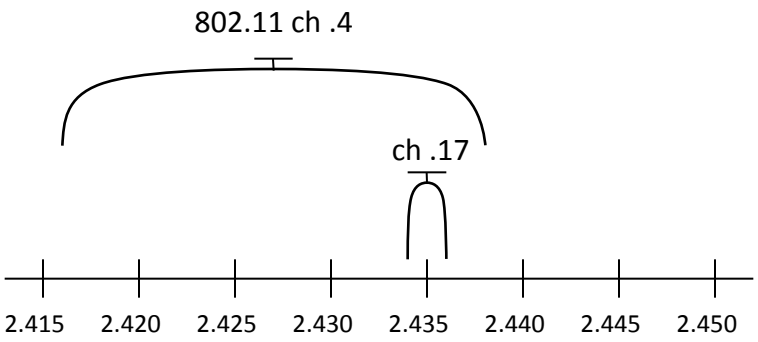


ZigBee, 802.11 Coexistence Investigated

- **Two representative interference patterns:**
  - Wi-Fi ch. 6 interferes with ZigBee ch. 17 near its center frequency
  - Wi-Fi ch. 4 interferes with ZigBee ch. 17 in its sideband



direct

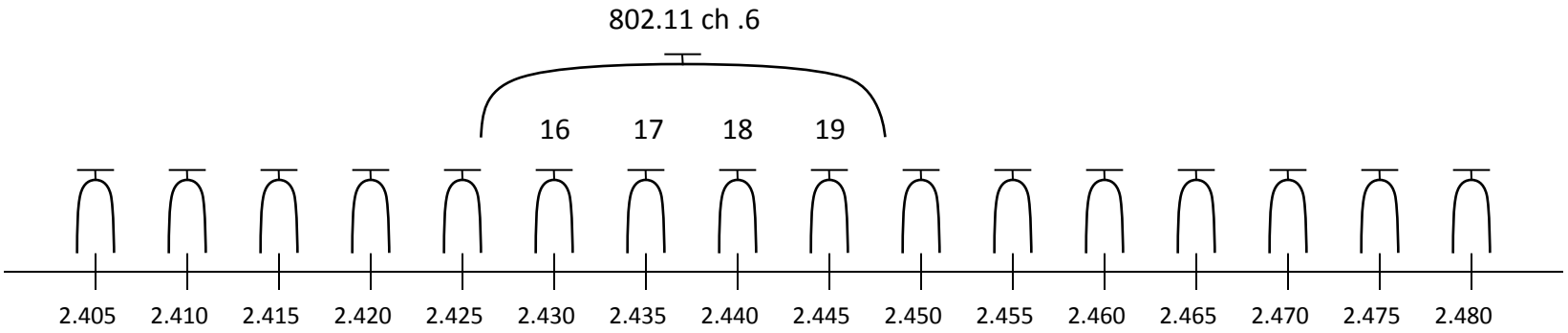


sideband

ISA100, 802.11 Coexistence Investigated

- **One representative interference pattern:**

  –Wi-Fi ch. 6 interferes with ISA100.11a ch. 17/18 near its center frequency, ch. 16/19 in its sideband



ZigBee, ISA100 Performance Evaluation Methodology

- **Primarily concerned with performance under RF interference conditions:**
  - measure message delivery rate (related to goodput)
  - configure 5 nodes in star topology (primarily tests MACs)

- **IEEE 802.11g router used as interference source:**
  - traffic generated between laptop (wireless to router) and workstation (wired to router) using Iperf
  - flows considered: 0 Mbps, 5 Mbps, 10 Mbps, 20 Mbps
  - also considered maximum single-flow (~ 30 Mbps)

- **Maximum-length packets sent using each protocol at several periodicities:**
  - Packet lengths: 76B
  - Packet periodicities: 1 s/packet, 5 s/packet, 10 s/packet
  - Experiment duration: 1 hour
  - Averaged over 3 trials
  - ~ +3 dBm output power selected for both WSN platforms

ZigBee, ISA100 Performance Evaluation Hardware

- **JSC WSN node (ISA100.11a):**
  - Nivis VN210 radio, TI MSP430-F5438 microcontroller

- **TI MSP430 Experimenters Board (ZigBee Pro):**
  - TI CC2530 radio (ZigBee Pro stack), TI MSP430-F5438 microcontroller
  - looks identical to custom ZigBee JSC node from application code point of view
  - low-cost stand-in for custom hardware

ZigBee Pro

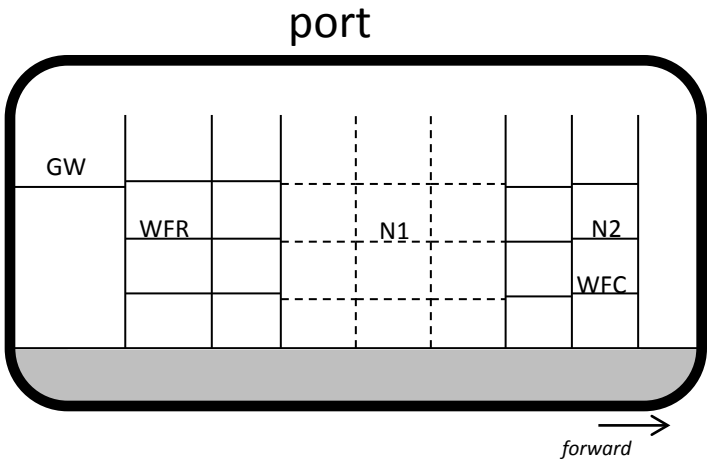
ISA100.11a

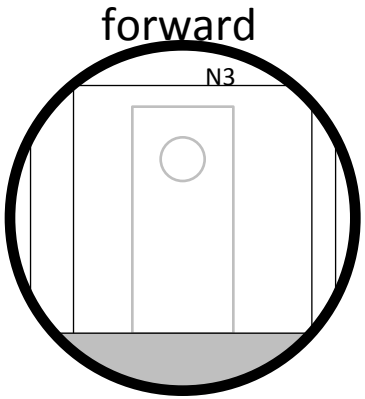
Testbed Environment

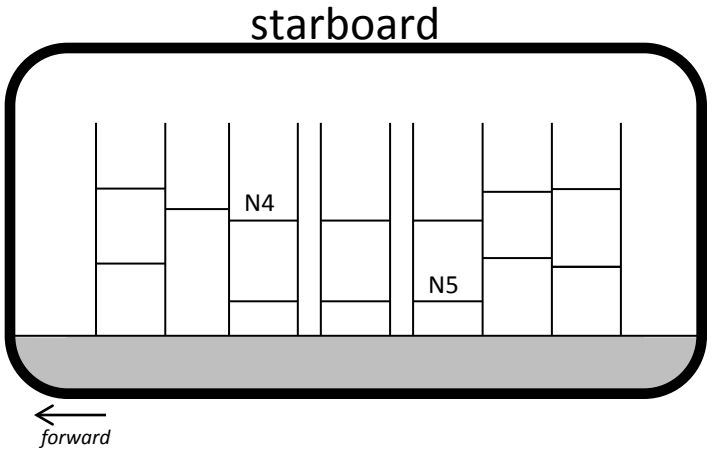
JSC wireless habitat test bed:

- Provides representative, crewed environment for controlled studies
- Good isolation from external RF environment, high level of internal multipath
- Allows interferers to be selectively introduced

Test Hardware Layout



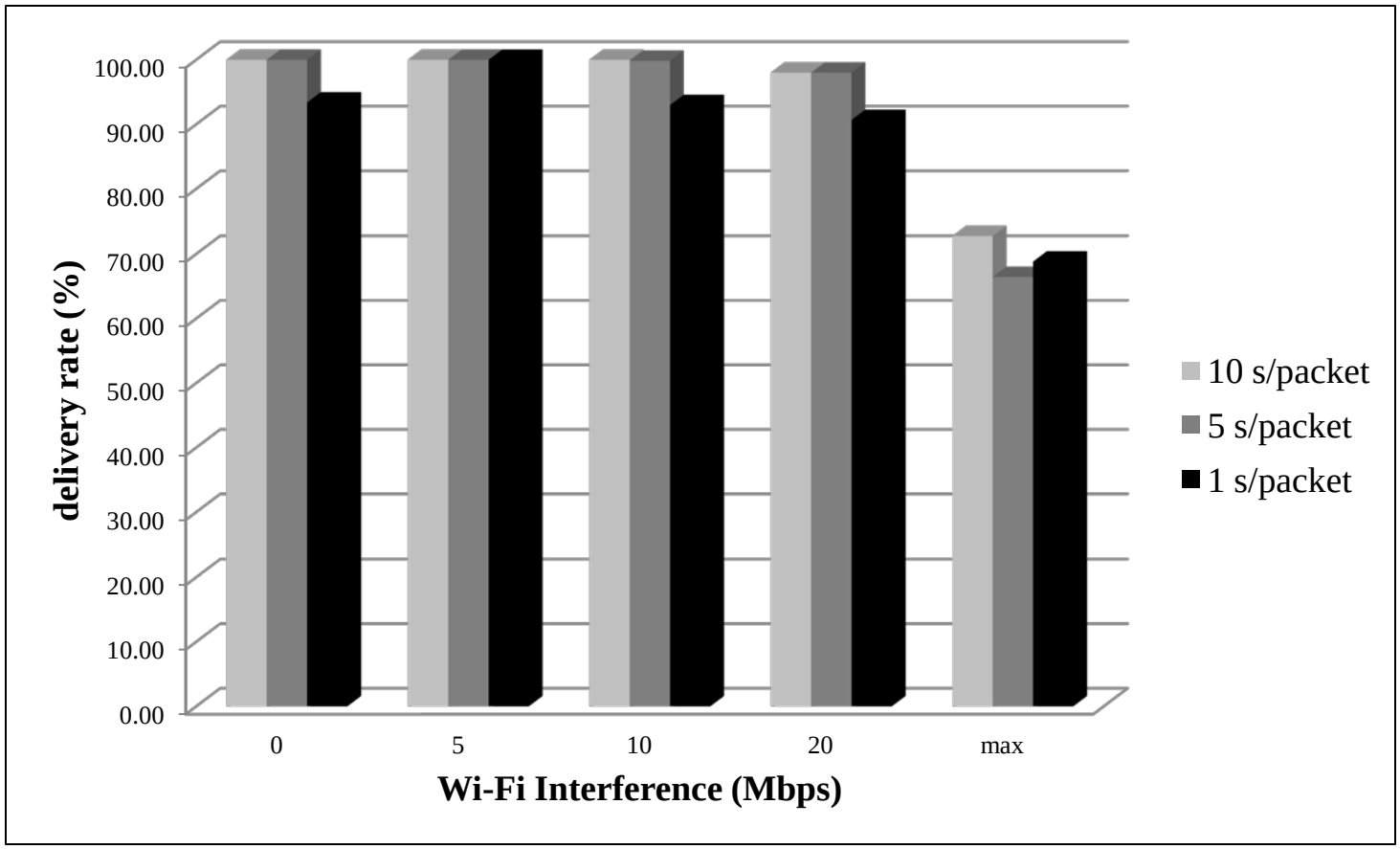




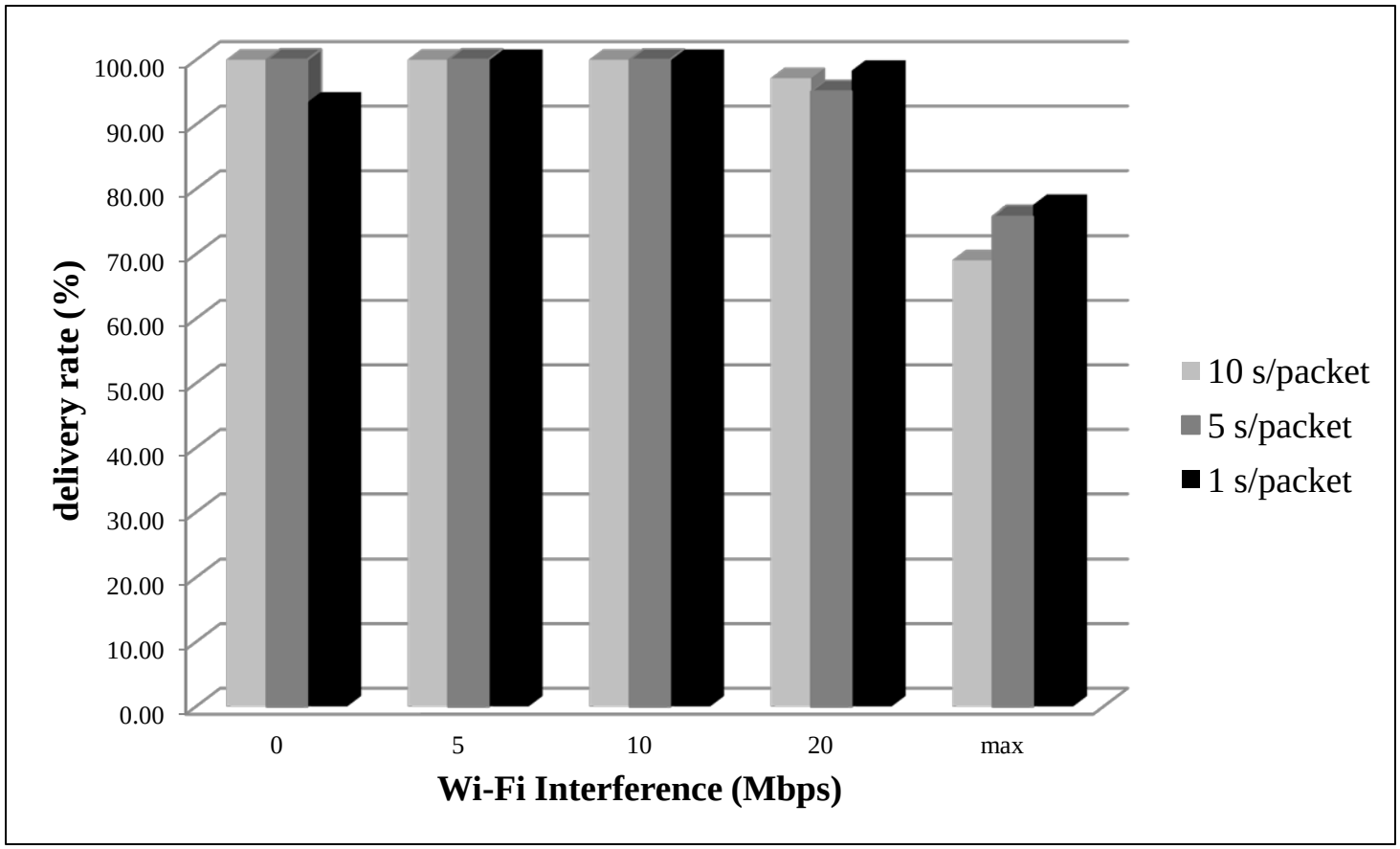
legend:

- GW – WSN gateway
- N1-N5 – WSN nodes
- WFR – Wi-Fi router
- WFC – Wi-Fi client

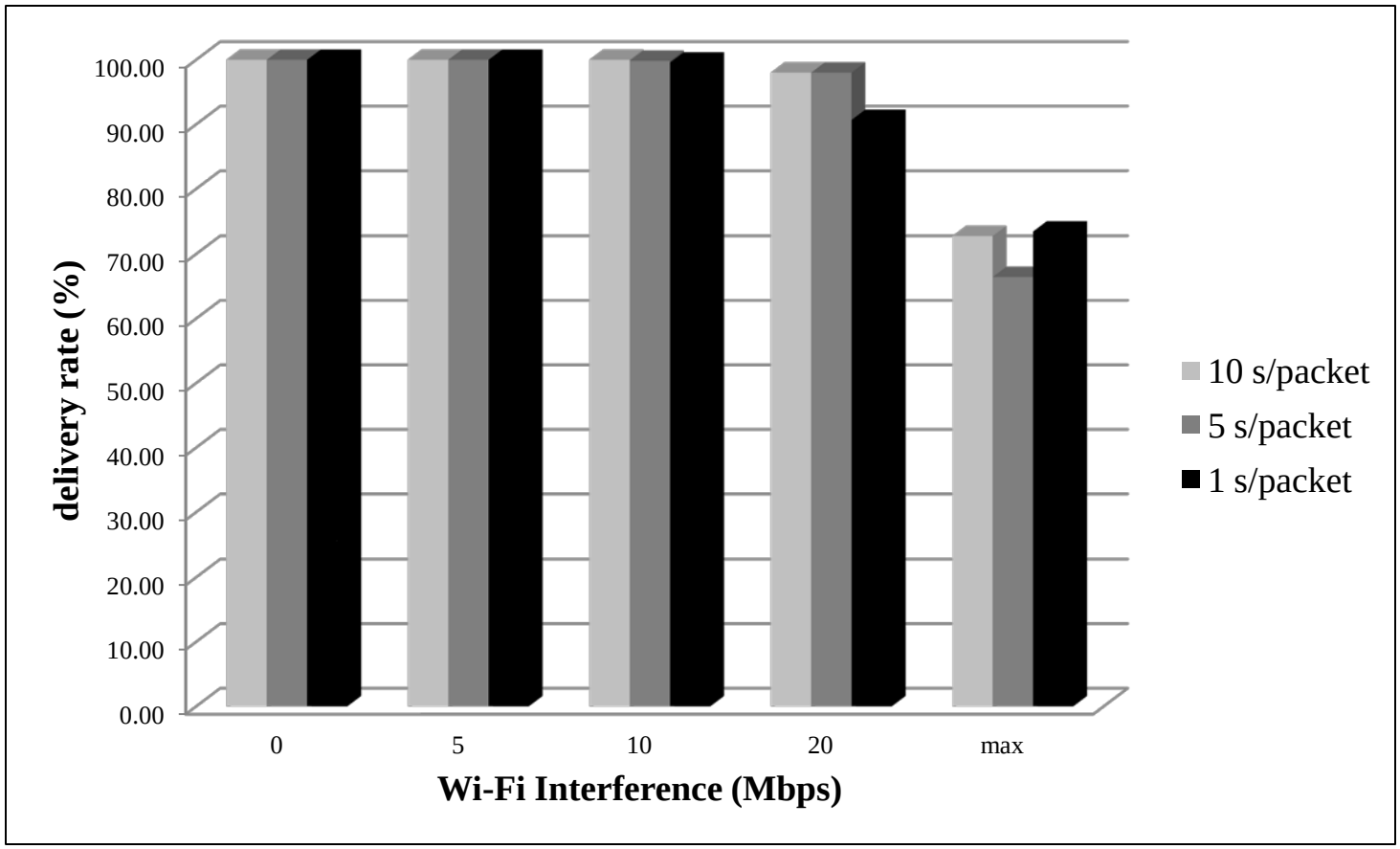
ZigBee – Direct Interference



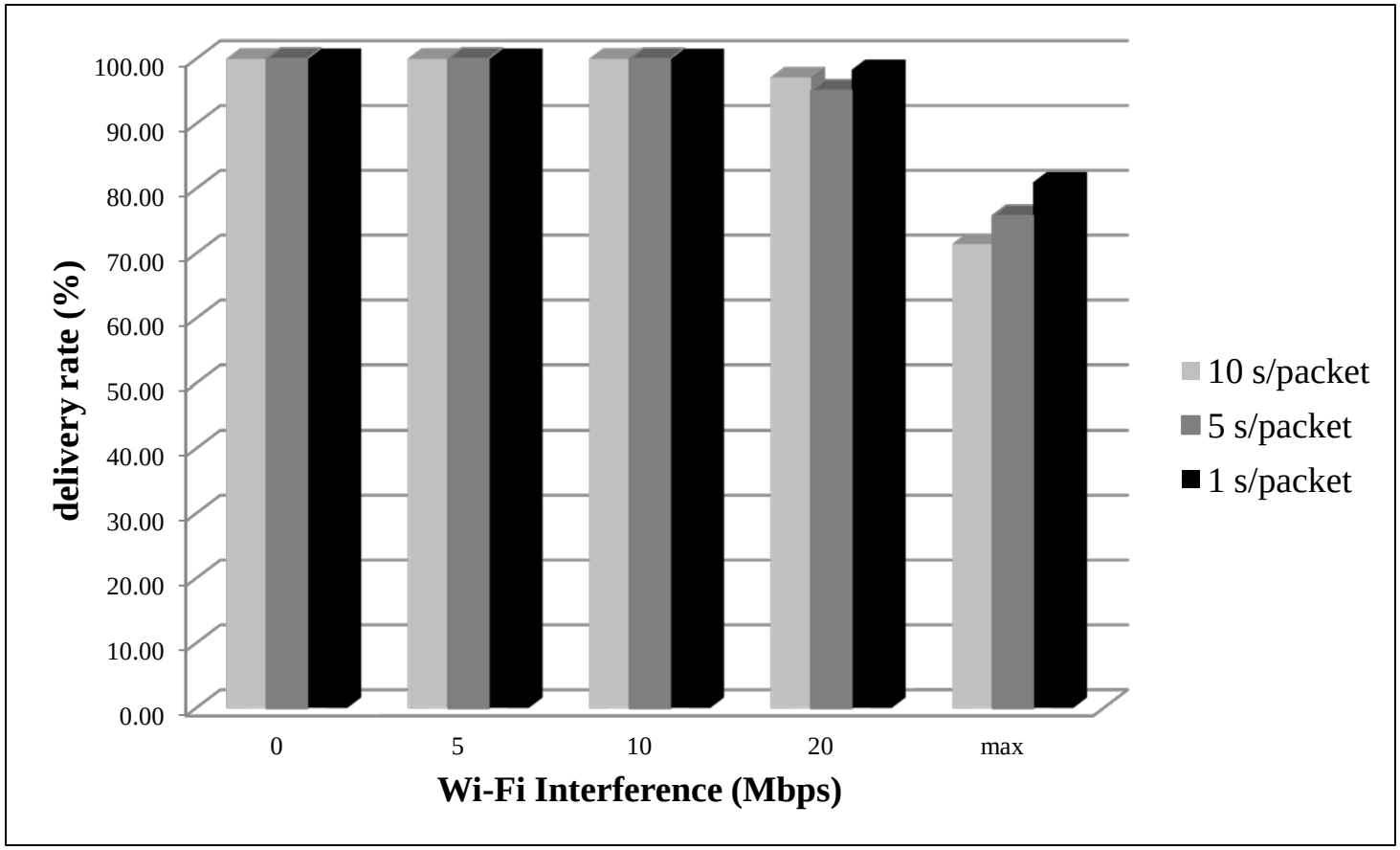
ZigBee – Sideband Interference



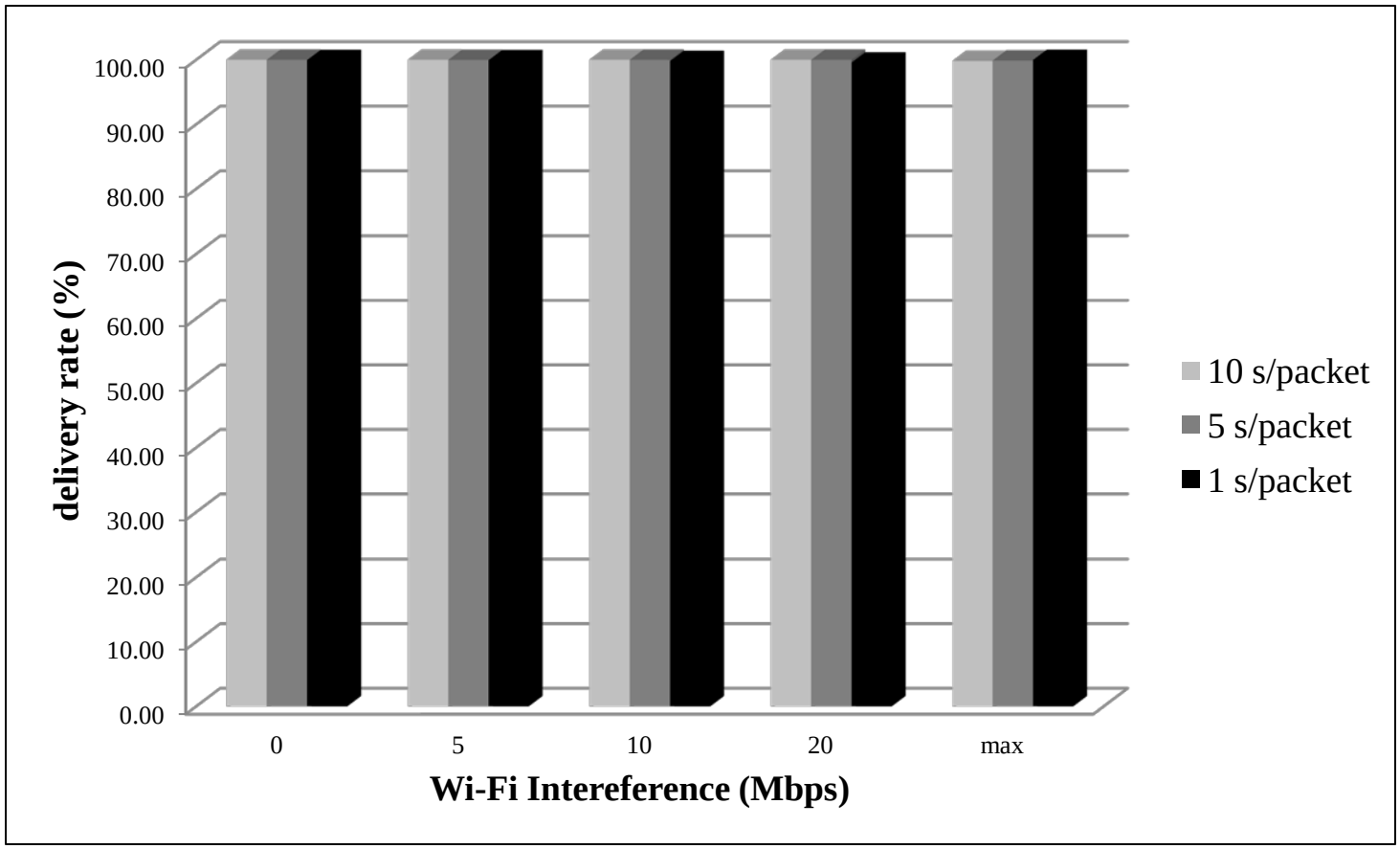
ZigBee – Direct Interference (outliers removed)



ZigBee – Sideband Interference (outliers removed)



ISA100

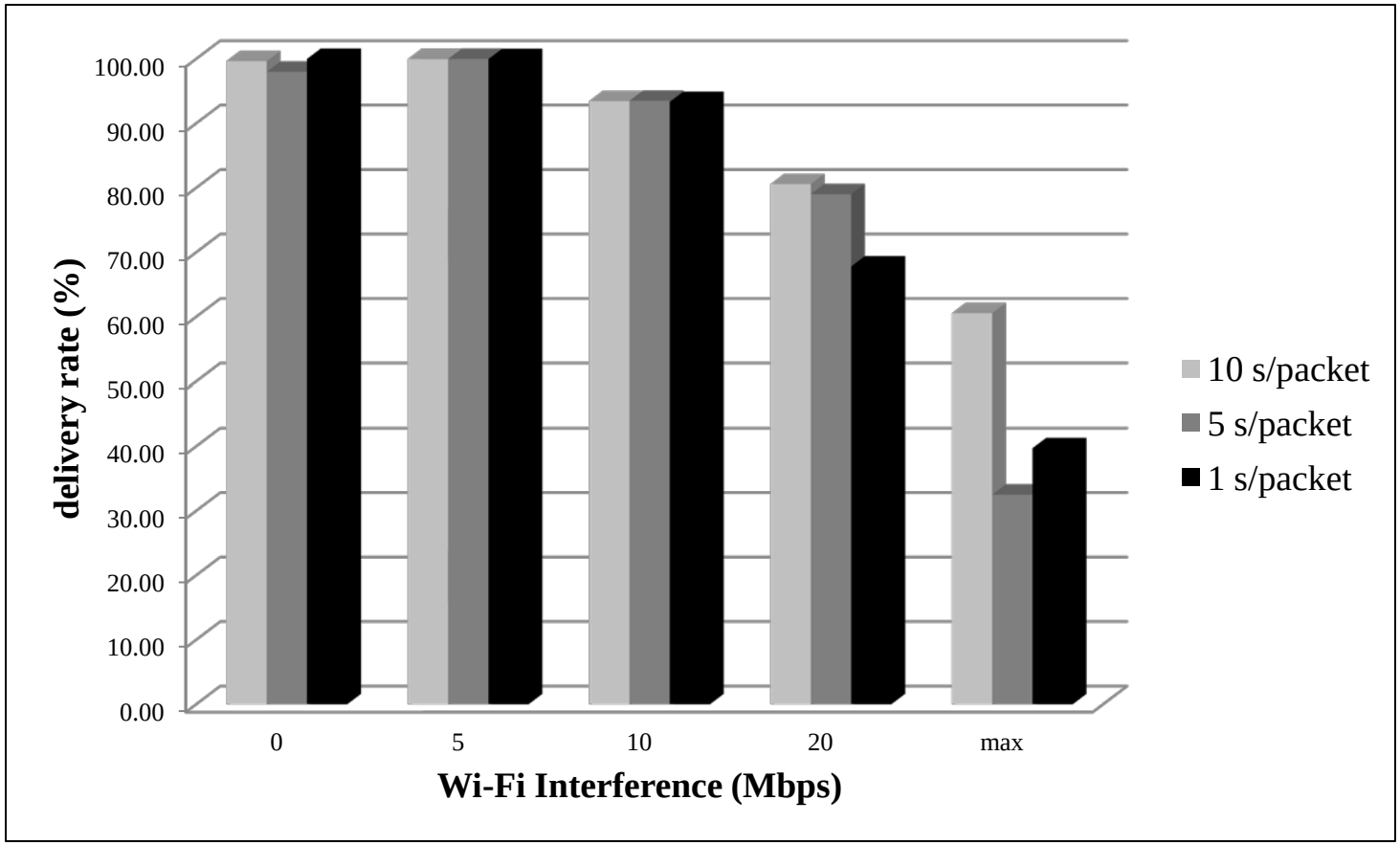

100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
delivery rate (%)
0
5
10
20
max
Wi-Fi Intereference (Mbps)
10 s/packet
5 s/packet
1 s/packet

Comparison Summary

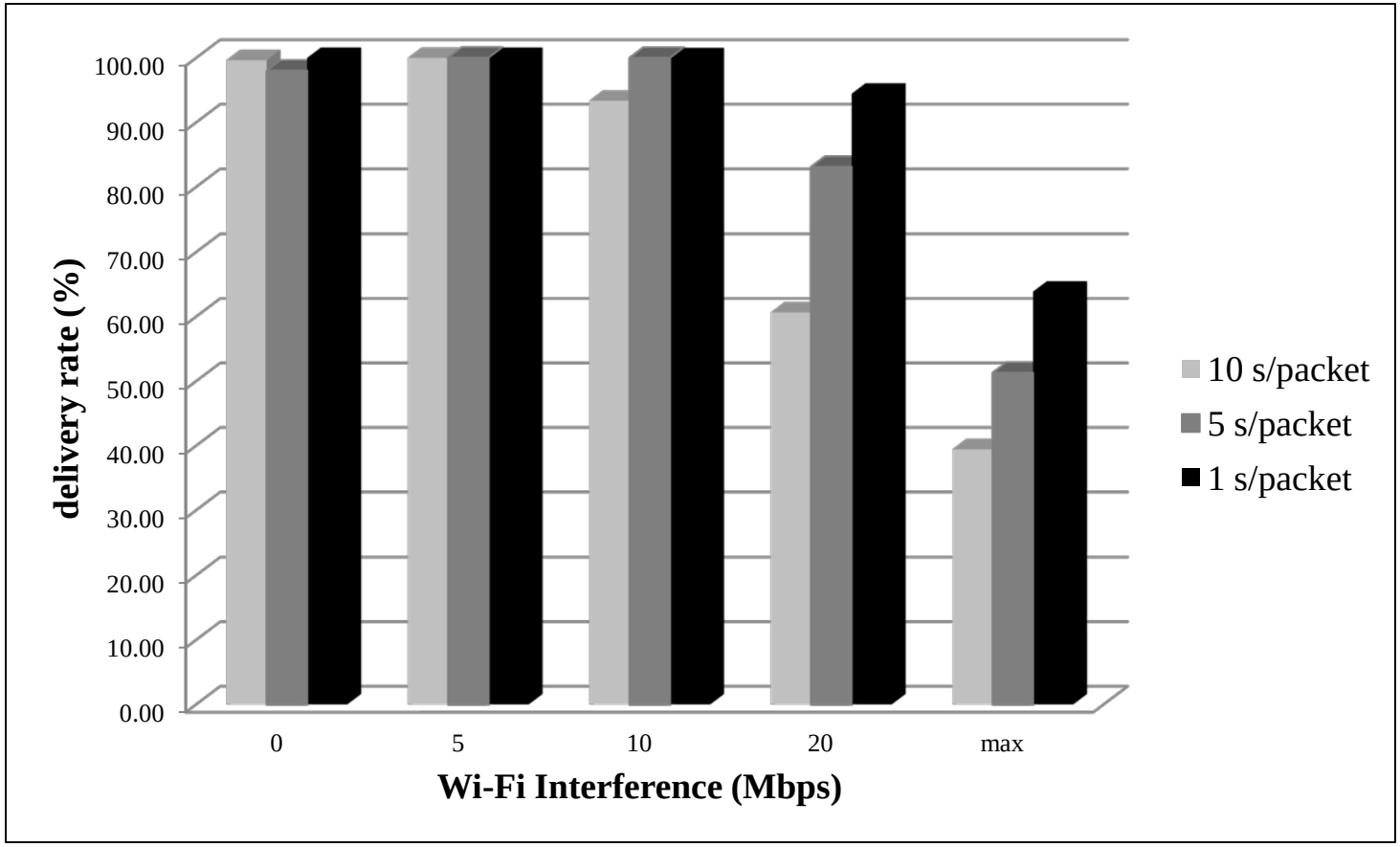
	Cost	Network Setup	Throughput	Latency	Interference Tolerance
ZigBee Pro	~$10/unit	instant-on	higher	variable	low-to-moderate
ISA100.11a	~$120/unit	centralized optimization	lower	bounded	high

(results appear in *Performance Comparison of Wireless Sensor Network Standard Protocols in an Aerospace Environment: ISA100.11a and ZigBee Pro,* R. Wagner and R. Barton, 2012 IEEE Aerospace Conference)

ZigBee – Direct Interference (-3 dBm)



ZigBee – Sideband Interference (-3 dBm)



Conclusions

- **Completed first head-to-head comparison of ZigBee Pro, ISA100.11a presented in the literature**

- **Found that both ZigBee and ISA100.11a have their places**
  - ZigBee: inexpensive, fast network formation, better throughput, good at lower interference levels
  - ISA100.11a: better latency guarantees, more robust at higher interference levels

- **Uncovered occasional ZigBee Pro node disconnections**
  - sometimes intermittent, sometimes permanent
    - ~ 1% of time at +3 dBm output power
    - ~15% of time at -3 dBm output power
  - correlated most strongly with high interference, but happened on occasion at lower interference levels

Forward Work

- **Further characterize ISA100.11a performance:**
  - performance with two or more 802.11 interferers?
  - maximum achievable throughput in closed environment?

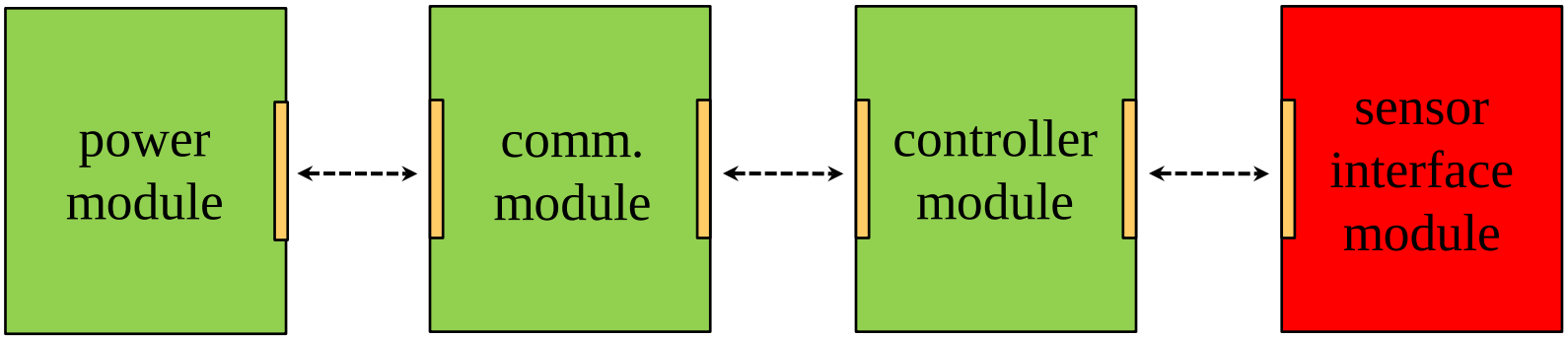
- **Further characterize ZigBee Pro performance:**
  - maximum achievable throughput in closed environment?
  - what causes orphaning?

- **Compare ZigBee multi-hop routing approach (AODV) with ISA100 (graph)**

- **Explore effects of 802.11n interference**

Update on JSC Modular Wireless Instrumentation (“SSIART-NASA”)

JSC Modular Instrumentation (MI) Architecture



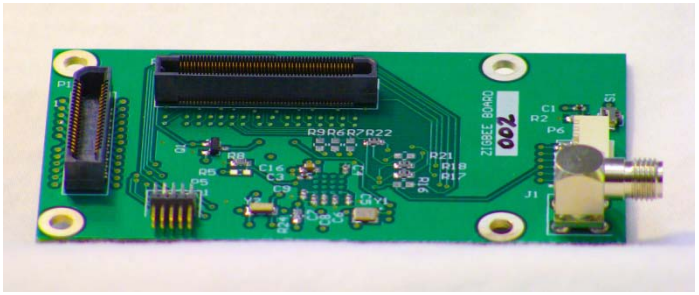
- battery
- energy harvesting (e.g., solar, vibration)
- mains (wired)

- handles data transport to C&DH system
- forms common network with other nodes
- can be wired or wireless

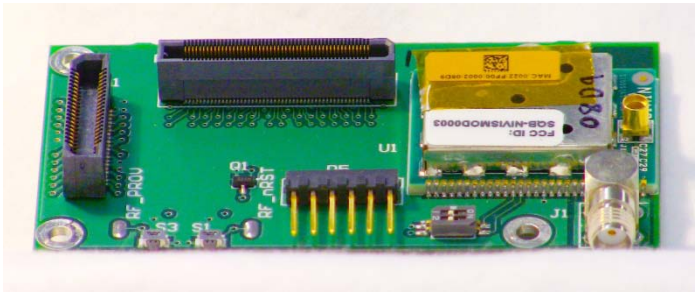
- manages data acquisition
- processes sensed data as needed
- formats data for transport to C&DH

- provides application-specific sensors, sensor conditioning
- only custom-designed component

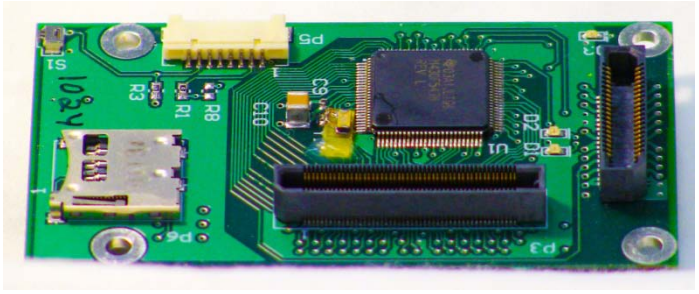
JSC MI Components



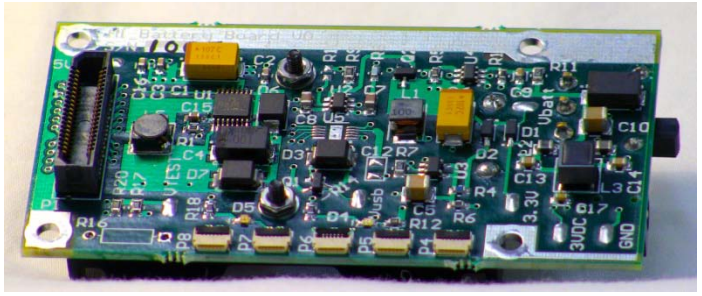
ZigBee Pro radio
(TI CC2530 ZNP)



ISA100.11a radio
(Nivis VN210)



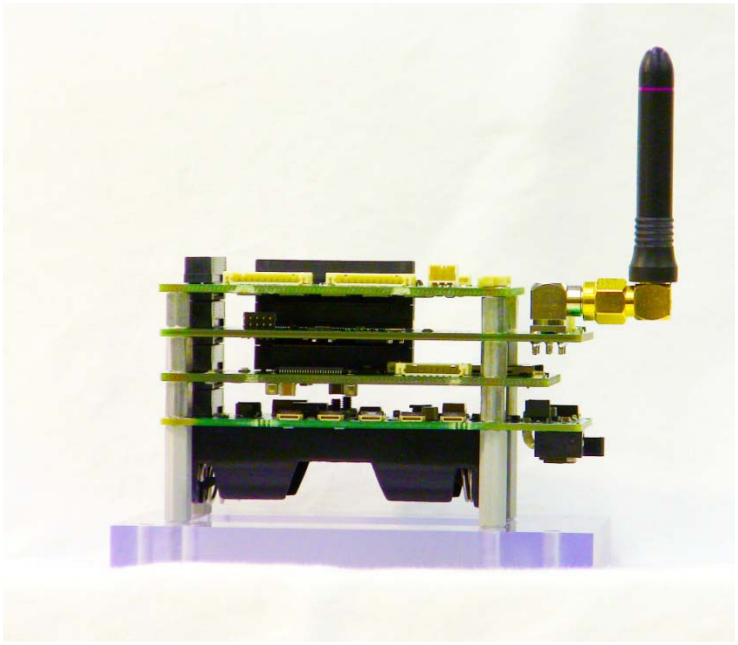
processor
(TI MSP430-F5438,
MSP430F5438a)



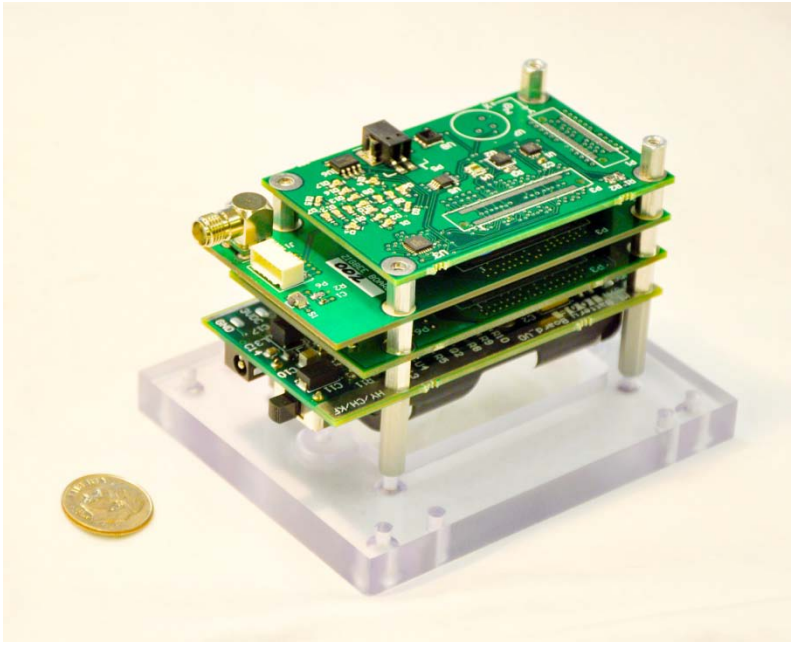
power
(9V wall, AA battery x2)

photos by Mary Lynne Barends, NASA-JSC

Modular Instrumentation Stack



side view
(with sensor package)



scale view
(with sensor package)

photos by Mary Lynne Barends, NASA-JSC

Modular Instrumentation Mechanical Interface

Interface Specification:

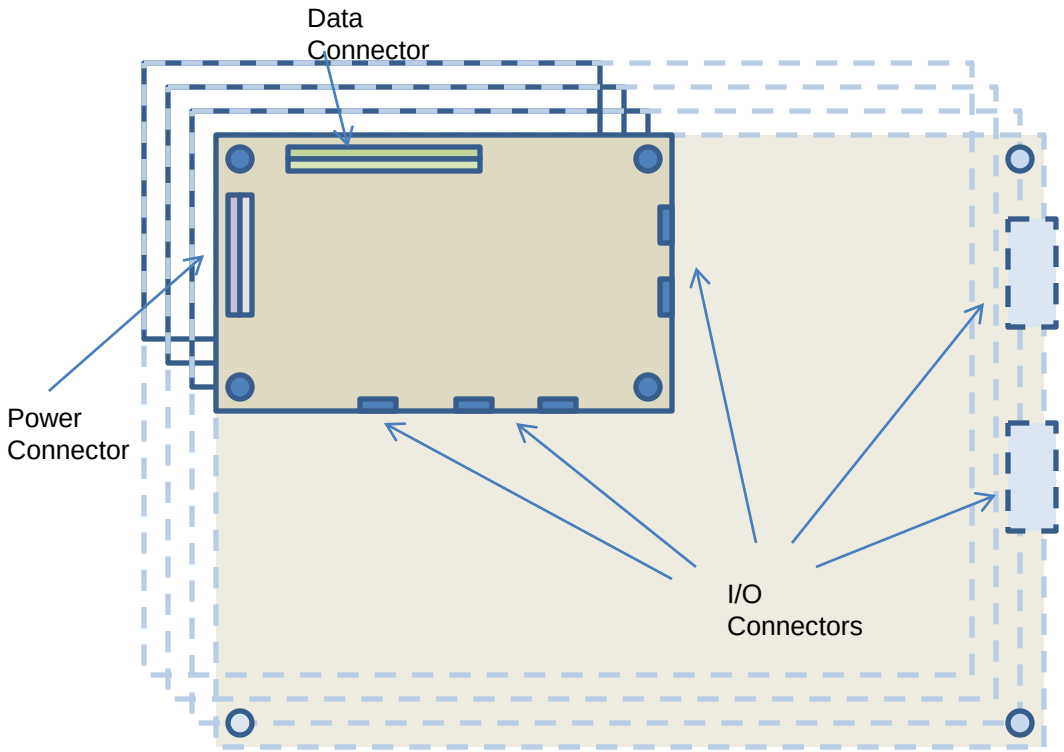
•board dimension user-defined

• mounting hole locations pre-defined

• data connector location, pin assignments defined

• power connector location, pin assignments defined

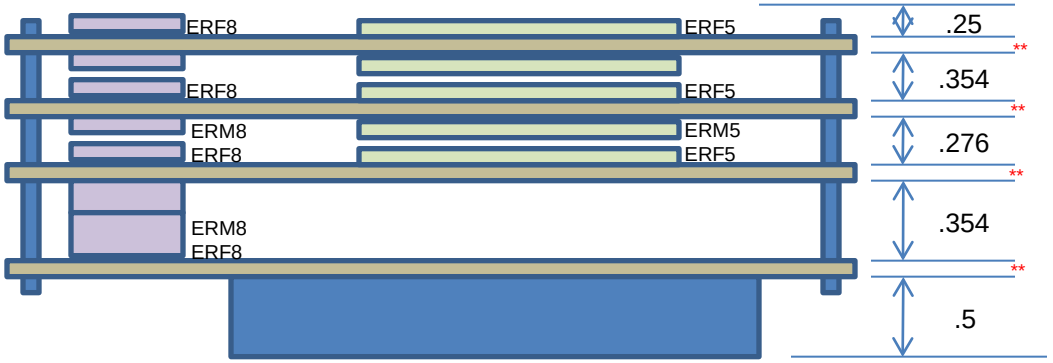
• I/O connector types, locations user-defined



Modular Instrumentation Mechanical Interface

Board Clearance:

- Power, Data bus connector dimensions define board clearences
- mounting hole locations pre-defined
- data connector location, pin assignments defined
- power connector location, pin assignments defined
- I/O connector types, locations user-defined



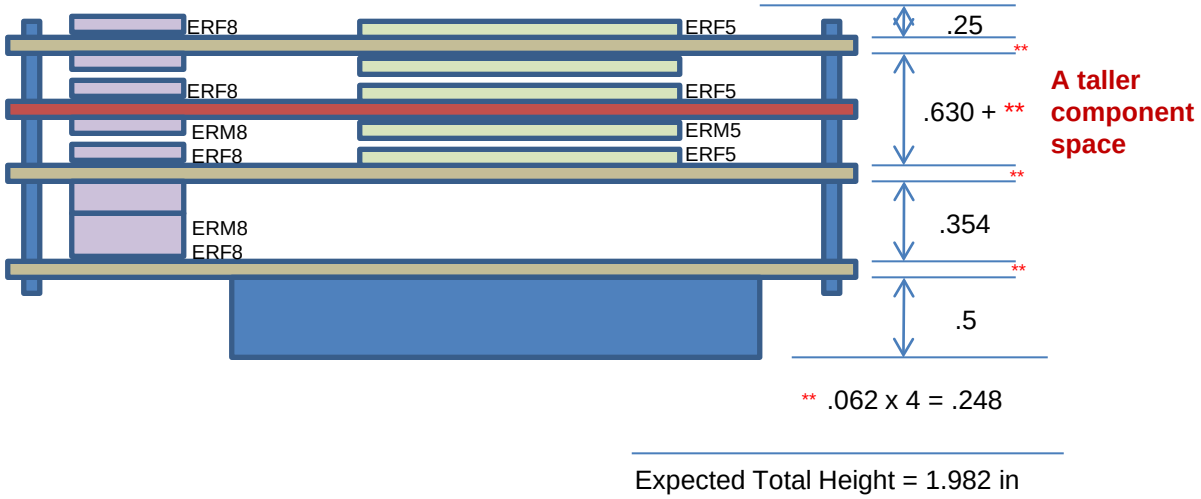
** .062 x 4 = .248

Expected Total Height = 1.982 in

Modular Instrumentation Mechanical Interface

Oversized Components:

- L-shaped adaptor can provide greater inter-board clearance



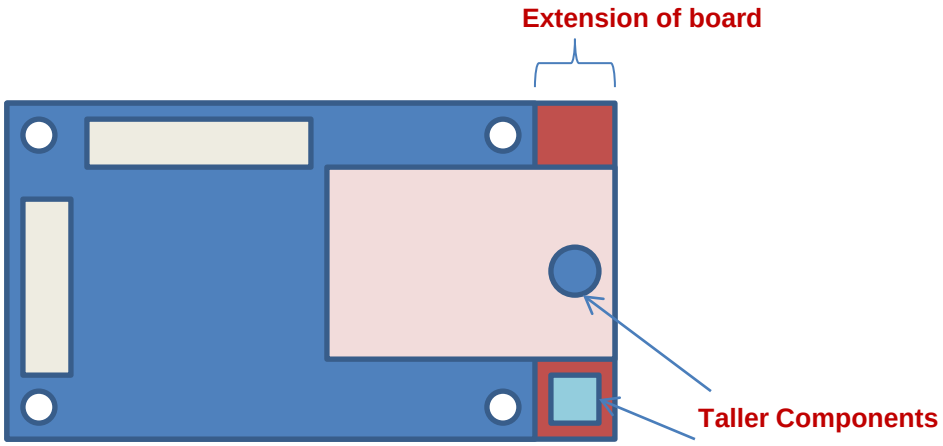
Modular Instrumentation Mechanical Interface

Oversized Components:

- Extending boards past nominal footprint can provide unconstrained vertical component space

** .062 x 4 = .248

Expected Total Height = 1.982 in



Update on JSC High-Speed Wireless Instrumentation Needs

Deep Space Habitat (DHS) Project

- **Project description**
  - Define and mature a DHS element that will enable human exploration beyond earth orbit (BEO)
  - Focus and Infuse habitat-related exploration technologies
  - Transition habitat-related products into the Habitat Demonstration Unit (HDU) prototype for integrated systems and mission testing
- **Current wireless capability**
  - ISA100.11a low-power, low data-rate WSN
    - Currently used for environmental monitoring and control
    - Primarily temperature and pressure data
  - EPCGlobal, Gen 1, Class 2 RFID
    - Inventory, tool, and sample tracking
- **Projected high data-rate wireless applications**
  - High frequency phenomena
    - Impact/leak detection and localization
    - Vibration/load monitoring during launch and docking
    - Structural health monitoring (shape and vibration)
    - Power transient monitoring
    - Non-destructive evaluation (NDE)
  - Real-time audio and HD video streams
  - Medical monitoring (very high priority)
    - Real-time telemedicine
    - Mobile crewmember monitoring
  - Increased security requirements to ensure privacy and data integrity

Project Morpheus

- **Project description**
  - Morpheus is a vertical test bed vehicle demonstrating new green propellant propulsion systems and autonomous landing and hazard detection technology
- **Current wireless capability**
  - 900 MHz, low data-rate command and telemetry ground link
  - 2 redundant UHF links for abort commanding
- **Projected high data-rate wireless applications**
  - Monitor high frequency phenomena on-board
    - Vibration/load monitoring during flight
    - Power transient monitoring in control systems
  - Real-time HD video streams
  - Stream full-bandwidth telemetry during flight
    - Enables real-time transient and diagnostic monitoring
    - Archive data to prevent total loss of data on vehicle malfunction
  - Wireless sensors for Autonomous Landing and Hazard Avoidance Technology (ALHAT)

Backup

ZigBee – Direct Interference

Interference Bandwidth:	Seconds Between packets	Test 1:	Test 2:	Test 3:	Average:	Std.Dev. of Tests:	Std. Dev. of Nodes:
0	1	100.00	100.00	80.17	93.39	11.45	25.60
5	1	100.00	100.00	100.00	100.00	0.00	0.00
10	1	80.13	99.82	99.00	92.99	11.14	25.54
20	1	83.39	94.31	94.35	90.68	6.32	5.88
max	1	73.50	56.65	76.32	68.82	10.64	18.99
0	5	100.00	100.00	100.00	100.00	0.00	0.00
5	5	100.00	100.00	100.00	100.00	0.00	0.00
10	5	99.81	99.94	99.78	99.84	0.09	0.34
20	5	97.92	99.39	96.75	98.02	1.32	2.09
max	5	58.50	69.56	71.25	66.44	6.92	12.83
0	10	100.00	100.00	100.00	100.00	0.00	0.00
5	10	100.00	100.00	100.00	100.00	0.00	0.00
10	10	100.00	100.00	100.00	100.00	0.00	0.00
20	10	97.83	98.89	97.33	98.02	0.79	1.95
max	10	71.22	74.89	72.22	72.78	1.90	4.70

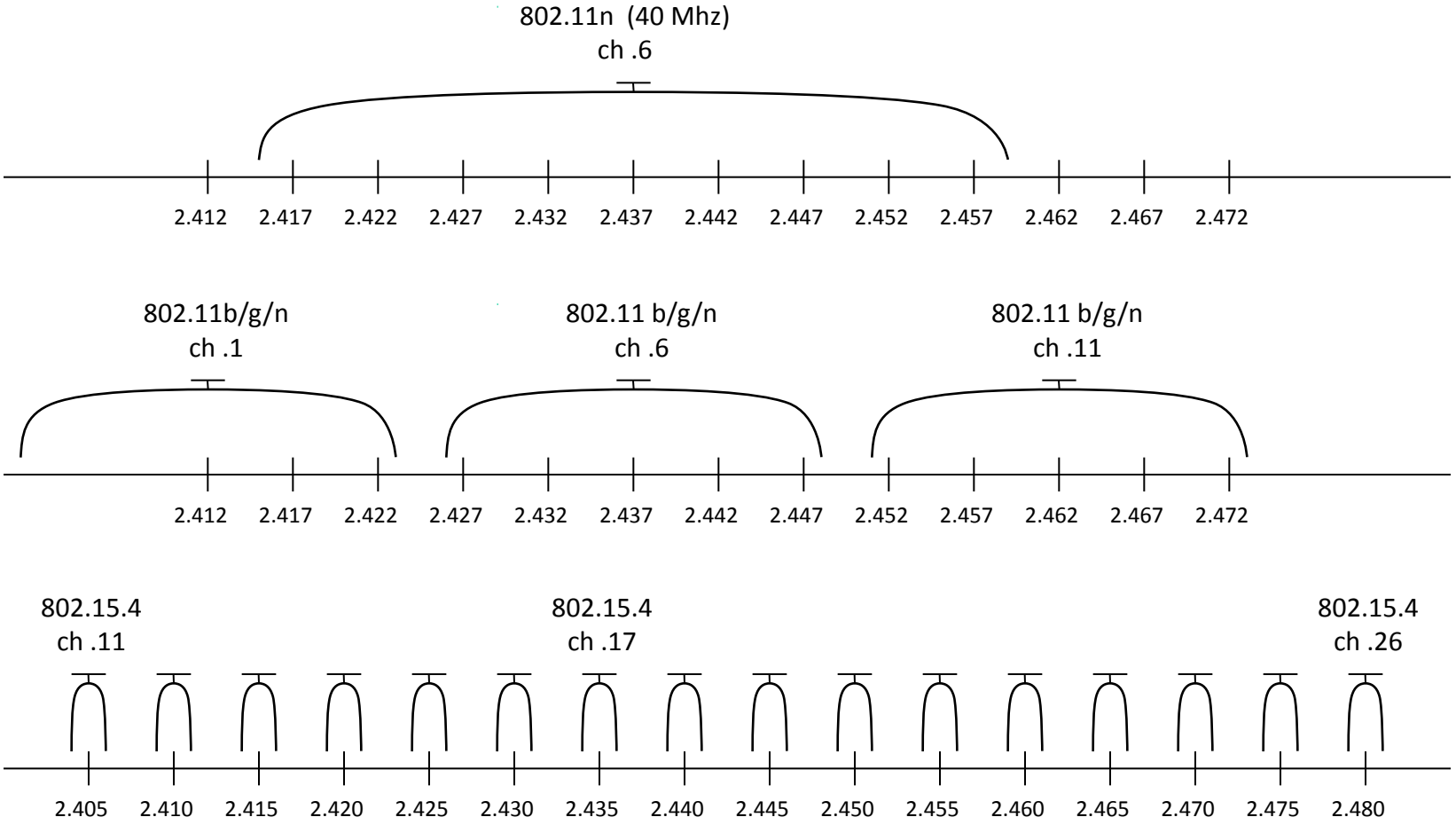
ZigBee – Sideband Interference

Interference Bandwidth:	Seconds Between packets	Test 1:	Test 2:	Test 3:	Average:	Std.Dev. of Tests:	Std. Dev. of Nodes:
5	1	100.00	100.00	100.00	100.00	0.00	0.00
10	1	100.00	99.98	99.98	99.99	0.01	0.02
20	1	99.26	98.74	96.93	98.31	1.23	1.88
max	1	81.32	69.45	81.78	77.52	6.99	14.05
5	5	100.00	100.00	100.00	100.00	0.00	0.00
10	5	100.00	100.00	99.97	99.99	0.02	0.04
20	5	90.44	96.28	98.58	95.10	4.19	4.42
max	5	74.50	77.39	75.39	75.76	1.48	4.13
5	10	100.00	100.00	100.00	100.00	0.00	0.00
10	10	100.00	100.00	100.00	100.00	0.00	0.00
20	10	97.06	95.83	98.56	97.15	1.36	2.36
max	10	71.39	66.11	69.56	69.02	2.68	10.75

ISA100

Interference Bandwidth:	Seconds Between packets	Test 1:	Test 2:	Test 3:	Average:	Std.Dev. of Tests:
5	1	99.93	99.95	99.96	99.95	0.015
10	1	99.94	99.92	99.94	99.93	0.012
20	1	99.72	99.96	99.74	99.81	0.133
max	1	99.43	99.92	99.37	99.57	0.302
5	5	99.97	99.97	99.98	99.97	0.006
10	5	100	100	100	100.00	0.000
20	5	99.97	99.94	100	99.97	0.030
max	5	99.97	100	100	99.99	0.017
5	10	100	100	100	100.00	0.000
10	10	99.88	99.83	99.94	99.88	0.055
20	10	100	100	100	100.00	0.000
max	10	100	100	100	100.00	0.000

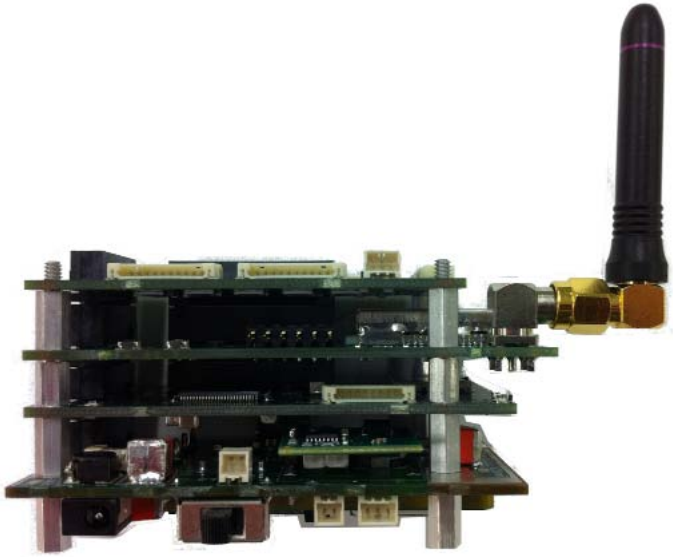
802.15.4, 802.11b/g/n Co-existence



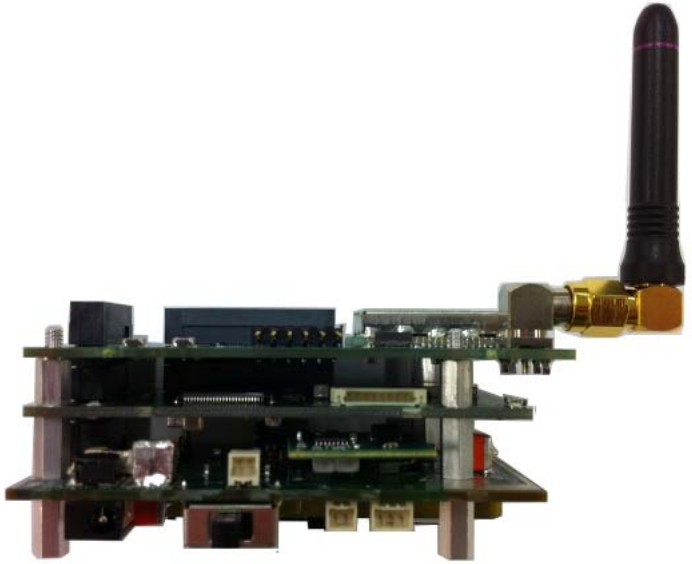
WSNs in the Wild

ISA100.11a node

Modular Instrumentation Stack



4 board stack
(inc. sensors)



3 board stack